frost. At the close of the month corn was mostly in shock, and buckwheat was mostly harvested, with fair yields of both. Late corn dried up, and was mostly cut for fodder. Pastures were very short and water scarce, but stock were in fair condition. Winter apples were being picked with prospects of about a half crop.—*E. C. Vose.*

Wisconsin.—A general frost occurred at most points in the interior on the 15th, 21st, and 22d. Pasturage was excellent for the season throughout the month, and fall seeding of winter wheat and rye obtained an excellent start. The rains interfered to some extent with the digging of potatoes, but a large crop was secured without damage. Much corn

failed to ripen and was cut for fodder. Apples were plentiful and of excellent quality.—*W. M. Wilson.*

Wyoming.—The month was favorable for the completion of haying and harvesting where that work was not completed during August. A good crop of grain was secured where the frosts of summer had not damaged the grain. Good range feed was general throughout the State, and stock were in excellent condition. The absence of any snow during the month over the greater portion of the State was very unusual for September.—*W. S. Palmer.*

SPECIAL ARTICLES.

A NEW THEORY OF FOG FORMATION.[1]

Translated by Frank W. Proctor.

[Interpolations by the translator are in brackets.]

Of all the theories concerning the formation of fog, but two have been accepted up to recent times, one of which is now universally held. But it will appear that both are not in harmony with our observations [Aeronautical Observatory, Royal Meteorological Institute of Prussia], and with the latest physical investigations; and accordingly we must seek a new explanation.

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The Davy-Dines theory [that condensation is due to the cooling of the earth's surface and its herbage by radiation] has been authoritative up to the present time, and is found in Hann's Lehrbuch der Meteorologie.

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In order to show that this explanation does not satisfy the facts, exact moisture measurements in the neighborhood of the earth's surface are necessary. These were made in 1893 by Homén[2]; and it was shown by him that fog can not arise simply through the radiation of the ground. In view of the great importance of those investigations to the present study, let us look into the matter more closely. Homén observed that the dew-point fell at the earth's surface and in the lower air layers when dew began to form. It follows that as soon as the air at the earth's surface has cooled below the dew-point, the water vapor condenses out of the stratum immediately above the earth's surface on the cold underlying surface. Thereupon the vapor pressure diminishes considerably in the lowermost layer, and the vapor from the layers above comes to the earth's surface by diffusion, where it, also, is condensed. Thus there occurs a continuous progression of the water vapor from above downward.

Homén maintained that the downward diffusion at the bottom went on faster than the incoming of moisture from above, so that in spite of steady decrease of temperature, saturation could not occur.

The observations of Hamberg[3] and Rubenson[4] had before yielded a similar result. Hamberg found, for example, that at the beginning of the night, at six and six-tenths meters height above the earth's surface, the relative humidity rose from 70 to 90 per cent, and toward the end of the night from 95 to 98 per cent. From these observations Homén drew the above-mentioned conclusion. Nevertheless it would be conceivable that in cases where the drying goes on more slowly than the cooling, light fog might form.

On the answer to this last question, viz, whether the drying can proceed more slowly than the cooling, the decision in regard to the hitherto prevailing fog theory depends. Homén could have answered this through observation by means of his dew-point measurements[5] of August 12-13 and September

6-7, had he secured trustworthy synchronous temperatures. Then it would have appeared whether the cooling of the air, i. e., the conduction of heat, goes on faster than the diffusion of the water vapor. This question must therefore be answered in another way.

If we assume that at the height of one centimeter above the earth's surface, the air is saturated at t_1^0 while at the earth's surface dew making begins at t_0^0, then in the course of time vapor will diffuse from above downward, while simultaneously the higher temperature approaches the lower through conduction. For the sake of simplicity, let us assume that during the whole time the temperature of the earth's surface remains at t_0^0. Thus it becomes warmed neither by condensation nor through the importation of heat from above, and is not cooled through radiation, which is the more admissible as the different influences will more or less offset each other. The upper layer will thus finally acquire the temperature t_0^0 of the lower. Condensation will now begin in the upper layer if the vapor tension is at least equal to the vapor tension at t_0^0, or if less than the difference of water content which can exist in the air at t_1^0, and t_0^0 is diffused in the same time that is needed for the difference of heat $t_1^0 - t_0^0$ to pass by conduction through one centimeter.

A calculation of this kind, however, is not easily made. The same result is more conveniently reached if we calculate, on the one hand, the time required for the difference of water content of saturated air at t_1^0 and t_0^0 to diffuse through one centimeter, and, on the other hand, the time necessary to transmit a temperature difference of 1° one centimeter in the air.

It follows, then, that if the conduction of heat proceeds more rapidly than the diffusion of the water vapor fog formation can take place. In the opposite case, this is impossible.

The quantity, S, of a gas which in time Z passes by diffusion through a cross section, q, of a tube l centimeters long, when the density of the gas is d_0 at one end of the tube and d_1 at the other end, is, as is well known, expressed by the formula

$$S = kq \frac{d_1 - d_0}{l} Z,$$

or, when $d_1 - d_0 = d,$

$$S = kq \frac{d}{l} Z, \qquad (1)$$

where k is the coefficient of diffusion, i. e., the amount of gas which is transmitted through cross section 1 when all the other quantities on the right-hand side of the equation $= 1$.

For the present case we assume $q = 1$, and according to the foregoing assumption $l = 1$; then it follows that

$$Z = \frac{S}{kd}.$$

S is the quantity of water vapor diffusing in one cubic centimeter of air.[6] This amounts, at a vapor pressure[7] of e_1, to

$$S_1 = 1.060 \frac{e_1}{1 + at_1} 10^{-6}.$$

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[1] *Extract from* Die Entsthung und Alflösung des Nebels von Hermann Elias. Berlin, 1904. *Reprinted from* Ergebnisse der Arbeiten am Aeronautischen Observatorium, 1 Oktober, 1901, bis 31 Dezember, 1902.

[2] Homén. Bodenphysikalische und meteol. Beobacht, 1894, p. 171 ff.

[3] Hamberg. Om nattfrosterna, etc., 1874. p. 84 *and* La température et l'humidité de l'air à differentes hauteurs. Nova Akta R. S. S. Upsaliensis. 1879, Vol. X, No. 4.

[4] Rubenson. Om temperatur-och fuktihetsförhållandena, etc. Öfversigt af K. Sv. Vet. Akad. Förhandl. 1875, No. 1.

[5] Homén. A. a. O., pp. 174-175.

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[6] S is here the quantity of water vapor whose time of diffusion through one centimeter of air is to be calculated. S_1 and S_0 are the total amounts of water vapor in one cubic centimeter of saturated air at temperatures t_1 and t_0, respectively.—*F. O. S.*

[7] Hann. Lehrbuch der Meteorologie, p. 219.

At vapor pressure e_0, $S_0 = 1.060 \dfrac{e_0}{1 + at_0} 10^{-6}$.

Whence, $\quad S = S_1 - S_0 = 1.060 \left(\dfrac{e_1}{1 + at_1} - \dfrac{e_0}{1 + at_0} \right) 10^{-6}$.

The density d_1 is the weight of a cubic centimeter of water vapor at tension e_1 and temperature t_1, thus

$$d_1 = .0623 \times 1293 \frac{e_1}{760\,(1 + at_1)} 10^{-6} = 1.060 \frac{e_1}{1 + at_1} 10^{-6};$$

likewise, $\quad\quad d_0 = 1.060 \dfrac{e_0}{1 + at_0}$,

or $\quad d = d_1 - d_0 = 1.060 \left(\dfrac{e_1}{1 + at_1} - \dfrac{e_0}{1 + at_0} \right) 10^{-6}$.

It appears, as was to be expected, that $d = S$. Then will

$$Z = \frac{1}{k},$$

and the coefficient ·of diffusion, according to Winklemann, is about 0.20; so we find that

$$Z = \frac{1}{0.20} = 5 \text{ seconds.}$$

Thus the time which the vapor of saturated air needs to reach the layer of air of lower temperature one centimeter distant is five seconds, regardless of the temperature.

The calculation of the time that is needed for the conduction of 1° [the temperature scale throughout is centigrade] of temperature along a track of one centimeter is simpler. The thermometric conductivity of air, that is to say the amount of heat which in one second traverses a cube with one centimeter sides, if we take as the unit of heat the quantity of heat necessary to raise the temperature of this substance 1°, is equal to .173;[8] therefore $Z = \dfrac{1}{0.173}$ seconds needed to allow the whole heat unit to pass through the cube or to conduct 1° from one surface to the opposite one. Therefore

$$Z = 5.78 \text{ sec.}$$

For any other temperature gradient the time of conduction will be inversely proportional to the gradient; hence

$$Z = \frac{5.78}{t_1 - t_0} \text{ sec.}$$

By comparing both times it is seen that the conduction of temperature is accomplished in the same time as the diffusion [of vapor] when

$$5 = \frac{5.78}{t_1 - t_0}, \text{ i. e., } t_1 - t_0 = \frac{5.78}{5.00} = 1.16.$$

Gradients of that strength are not found, the strongest observed by Juhlin[9] amounted to 2° in three centimeters, thus 0.67° centimeter, i. e., temperature equalization would have required 8.7 seconds; therefore much more than the time required for diffusion. We are therefore warranted in concluding that before the low temperature of the surface arrives at the upper stratum, assumed to be saturated at the outset, the upper layer has lost so much vapor that it is then reduced below the saturation point.[10]

The results for the two quantities would change in the same proportion if a thicker portion of air and thus a smaller gradient were taken. The time which the temperature uses increases exactly as the distance; so, also, does the diffusion period, as is seen by formula (1) in which Z appears in the numerator and l in the denominator.

In the foregoing calculation no account is made of the in-

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[8] Hann. Lehrbuch der Meteorolgie, p. 10.
[9] Juhlin. Sur la temp. nocturne de l'air à diff. haut. Soc. R. de Sciences d'Upsal. 1889, und Met. Zeitschr. XXV, 1890, p. 73.
[10] Apparently the author does not take into account the cooling of the upper stratum by radiation.—*F. O. S.*

flowing of vapor from above. This will modify the conclusion with regard to the time of diffusion. Whether this time can not be greater than the time of temperature conduction should not be passed over without further comment. It is seen by the calculation that the velocity of movement of water vapor in saturated air is only 0.2 centimeter = 0.002 meters per second, thus considerably smaller than any even feeble air movement, so that the distribution of water vapor in the vicinity of the earth's surface is not determined by Dalton's law, but by the kind and velocity of air movement. Therefore the objection that the inflow of vapor from above makes the diffusion period greater than the time of temperature conduction becomes of little force.

But if Dalton's law be assumed as admissible near the surface of the earth, fog can exist purely through the agency of radiation only when the temperature gradient reaches enormous values.[11]

This last assertion is supported by the fact that it is never found that fog at first forms directly on the earth's surface and grows from below upward, and by the further circumstance that in the example of double windows where the conditions are precisely similar to those in fog formation at the earth's surface (because the outer window is much cooled opposite the inner air), a clouding of the air is never observed, but at once a condensation of the vapor on the outer window. Also in our many ascents at which great temperature inversions with frost and dew were found, and thus saturation occurring at the earth's surface, nevertheless fog has not been observed.

The first beginning of fog formation has unfortunately been observed but once, though the ascents generally occurred in the early evening and morning hours; viz, when on October 27, 1901, fog was seen rising here and there in places, to which other causes contributed that will be discussed later; on the contrary December 17, 1901, furnishes so typical a case that the conclusion may be generalized at once. While about 3 p. m., without clouds, haze was noticed on the horizon, about 5:30 p. m. fog formed, not as if surface fog slowly extended itself upward, but as if the air up to greater heights, probably to over 50 meters, began to be turbid. The turbidity increased and toward the end of the ascent, with moderate fog, the characteristic billows (Wogen) of fog droplets could be plainly perceived. I had abundant opportunity also in the fall of 1902 to observe this kind of fog formation.

The vertical distribution of temperature and moisture at the ascent and descent, consequently before the beginning of fog formation and in the first stage of fog, have already been described and show nothing surprising. [They were for the ascent: temperature inversion from the earth to 100 meters, then temperature decrease to 175 meters, then a second increase to 250 meters, and thence upward the final decrease. On the descent the second inversion had disappeared, leaving a single inversion to 125 meters, and above a fall slightly less than the adiabatic rate. During both ascent and descent the relative humidity was constant from the earth to 500 meters, and the absolute humidity increased slowly up to 200 meters, and then decreased].

Otherwise the sudden setting in of a [pronounced] wind maximum at 100 meters which was theretofore feebly indicated at 200 meters height, is very noteworthy. The other meteorological elements from 3:30 to 6:30 p. m. had changed hardly any (the temperature at the earth had fallen from —4.6° to —4.9°, and the humidity increased from 85 to 86 per cent, both with little fluctuation; the barometer to be sure was falling rapidly, and dropped from 755.1 millimeters at 3:16 p. m. to 753.8 millimeters at 6:25 p. m.), so it is easy to connect the

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[11] We can hardly consider this as proven, since the author has just refused to take into account the influence of inflowing vapor from above, on the ground that Dalton's law is not admissible.—*F. O. S.*

change of wind velocity with the formation of fog. Yet it seems difficult to determine whether the increased wind movement was the result or the cause of the fog formation. An attempt to explain the large increase of wind velocity [from four to nearly eight meters per second] by the vertical temperature distribution has already been made; though in that place it was expressly stated that a satisfactory explanation could not be given, but that the cause of the gradients which produced the wind is doubtful.

The following considerations lead to the hypothesis that the increased air movement is a consequence of fog formation.

If it be assumed that before fog formation the air was saturated with vapor, then the pressure will be composed of the pressure of dry air and that of the vapor. If a portion of the vapor be condensed, then the vapor pressure at that place will become smaller; consequently also the whole pressure of air, without its being necessary for the barometer at the earth's surface to fall, for the weight of the whole air column has not been diminished. Thus at the place where the condensation occurs there must be a vertical gradient in the pressure which becomes a very light horizontal one if at some distance there is little or no condensation of vapor. This could therefore lead to a local wind that would be a result of fog.

Though it points to the contrary that the wind had increased up to 650 meters, though not so much as below—the increase [above] amounted to five-tenths to one meter per second—and further that on the next morning a very brisk wind prevailed which from 380 meters up to the greatest height attained grew to nearly six meters per second. In certain squalls, however, and overhead it was stronger, so that a further letting out of the balloon appeared impracticable. We therefore shall have to do, not with a local wind which was caused by fog, but with a temporary increase of air movement which reached up to great heights, and, therefore, on the evening of the 17th could not be preceived in the upper strata, because at the time the balloon was there the air movement had not appeared, but later and somewhat suddenly arose, brought about by the proximity of a low which made itself noticeable by the fall of the barometer. There remains, therefore, only the last possibility; that the wind, as soon as it attained a decided strength, caused the formation of the fog. This conclusion, standing directly contrary to the view generally prevailing hitherto, according to which fog formation is promoted by calms and dissipated by strong winds, shall be further supported by some observations.

On the 4th of November, 1901, in the morning, only very thin fog prevailed at the ascent, so that the balloon was still visible at 770 meters length of cable. Toward the end of the flight the fog thickened so that the balloon was first seen again at a distance of 100 meters. From the ascent to the descent a pronounced increase of the wind of nearly two meters per second was registered. Unfortunately we have no observations of the previous evening, but the ascent of the morning of November 3 showed very small wind velocity up to 100 meters (all the time under one meter per second), and it should be concluded that during the course of the night of the 3d and 4th, perhaps also in the early morning hours, it had so increased that it caused a condensation of the vapor.

If, now, proof is already furnished that strong vertical differences of wind velocity always prevail near the earth's surface when fog forms, it can also be shown that in cases where all the other conditions combine to favor fog making only trifling fog occurs, simply in default of sufficient differences of wind strength.

November 2, 1901, affords a typical example. At two high kite-balloon ascensions on November 1, one of which reached 2200 meters, the existence of an under, moist, cold, but feebly-moving current could be observed, which reached up to about 800 meters. Above lay what we have heretofore considered as characteristic of fog-making conditions; a warm and dry stratum with relatively small temperature decrease and somewhat brisker movement. Toward sunset the temperature had fallen to 1.2° at two meters height, and at the earth's surface to 0.2°, so that the temperature increase up to 95 meters, where 6.8° was registered, amounted to 6.6°. The relative humidity was constant at about 80 per cent up to this height. The conditions thus seemed favorable for fog formation, only it was nearly calm at the earth's surface; but between 120-400 meters the wind velocity amounted to three meters per second. On the next morning, with the exception of surface fog on the wet meadows in the neighborhood of the observatory, no fog was present, though the air up to about 75 meters was saturated. It now appeared that in the course of the night the wind velocity had further decreased, though from 30 meters up to 73 meters an increase from nine-tenths to two and seven-tenths meters per second was registered; but the wind decreased rapidly above, and at 275 meters was only one and two-tenths meters per second. In spite of the very strong temperature increase from —3.7° at two meters to +4.9° at 125 meters, i. e., of 8.6° in only 123 meters, and in spite of the high relative humidity, no fog formed. The coming clouds in the early morning could not be obstructive to the formation of fog, for, according to the view now prevailing, the air at the earth's surface would cool so much through conduction and radiation that the dew-point would be reached. These were in no wise impeded. Hence follow on the one hand the inadequacy of the kind of explanation hitherto advanced, and on the other the validity of the thesis herein advanced; that in fog formation the wind is a very active, yea, determining factor. As a further, if not so convincing, example, the 27th of October, 1901, could be cited. With especially favorable conditions only very thin fog formed, in consequence of a deficiency of wind.

In what manner the wind influences the vertical temperature distribution in the neighborhood of the earth's surface can be learned by a comparison of the condition curves of November 1 and 2, 1901, with those that were obtained in stronger winds.

While the influences of the cooling at the earth's surface on the evening of November 1 at one and a quarter hours after sunset extended up to about 100 meters, and on the next morning reached only 170 meters, we find that on the day before, with a brisk wind, which at 100 meters amounted to six meters per second, the cooling of the earth's surface was already perceptible at sunset up to 140 meters, with the condition of nearly a zero vertical-temperature gradient, which two and a quarter hours after sunset becomes an increase with height. There is seen by comparison of both condition curves[12] the essential difference of the march of temperature with little and with much wind. In the first case the inversion sets in at once at the earth's surface and attains a large value, but extends to a small height; in the second, on the contrary, the cooling is found in proportionately shorter time extended to a greater height, though not so strong. On October 30, with a wind of about ten meters per second at about 100 meters height at one hour after sunset, the cooling already extended to 184 meters, where the normal conditions became established. On October 28, finally, the highest temperature was reached some two hours after sunset at 150 meters, whereas the wind velocity at this height amounted to about seven meters per second.

This rapid cooling of the upper strata when there is wind can be explained only by the raising of the cooled air at the earth's surface. We have seen, in a former section, that billows form at the upper surface of fog, and indeed in the lower, denser

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[12] The figures which accompany the original text showing temperature, moisture, and wind velocity curves registered by the balloon and kite meteorographs are omitted.

medium as well as in the upper, thinner medium. Thereby the small particles of air derive not only vertical but horizontal motion. The same thing will happen whenever the wind pushes away the strongly cooled, lowest strata lying on the earth's surface, which have been hindered in their movement by friction. The cold air is lifted by sufficiently strong winds, and also assumes lateral movements and a kind of surging, which are favored by the unevenness and covering of the land, such as trees, houses, etc., and mixes itself with the warmer air and cools it. Only in this manner is it possible that the cooled air of the earth's surface arrives so quickly aloft. But when this air, which in general is near the saturation point, if not wholly saturated, comes in contact with the upper, warmer air-layers, and these also are relatively moist, then, as von Bezold has shown, there can be light condensation, which makes itself perceptible at first as a turbidity of the air, later as fog. The height to which moderate wind bears the air from the earth's surface appears, according to the tolerably harmonious observations of October 28, 30, and 31, 1901, to lie between 150 and 200 meters, and up to this height only would the first turbidity be able to reach. The diffusion of water vapor out of the upper into the lower strata can not go on so rapidly as the cold air is blown upward, although perhaps before the beginning of fog formation, in case dew forms, the layers next the earth dry out a good deal. The resulting mixture, however, does not depend upon the absolute water content of this layer, for if both air masses that are mixed together are near enough the saturation point, condensation occurs every time. Homén[13] has directly tested that kind of mixture of the dry air of the under layer with moister air from above, by measurements with the hygrometer. He found, for example, that at a height of about one and three-tenths meters the dew-point rose from 6° to 9° after a puff of wind. Here belong also the sudden increases of temperature in night radiations, which are readily seen by the thermograph, but whose explanation is difficult without the accompanying wind record. This kind of temperature increase is found at the surface of the earth with an accompanying rise of wind velocity, and the warming is due to the mixture of warm air coming from above with the cold air lying on the earth's surface. [To illustrate this, two tables of observations follow in the original, in which maximum temperatures are seen to coincide with increase of wind velocity.]

The first suggestion of the above-described explanation of fog was made by Köppen[14], if we have rightly understood his somewhat brief exposition. Berson[15] appears to have had a similar thought in mind, when, in the discussion of the before-mentioned balloon ascension of November 10, 1893, he traced the origin of the fog to the flowing away of the relatively warm and moist air over the earth's surface cooled by radiation; whereby he hints at the entirely characteristic feature of fog, as well as of billow formation at its upper limit which is easily recognized on an accompanying photograph, and of the causal relation therewith of sudden wind changes.

The following of the further stage of fog formation, after we have learned the origin, is not difficult. We saw earlier that from increase of temperature upward, in the further progress, zero gradients (Isothermie), and then decrease of temperature upward, develop. Equal temperature up to a certain height follows further mixing of the upper and lower layers, though it is necessary to that outcome that the cooling of the earth's surface go on more slowly than the air of the lower layers can be brought upward and come close under the corresponding warm air. This retarded temperature fall at the earth's surface follows from diminished radiation, which, as soon as a clouding of the air occurs, can no longer proceed

at the same rate as with clear sky. If, on the other hand, further radiation is entirely stopped by the coming in of a covering veil, or after sunrise when it would be compensated by the influence of the sun, then with stronger fog formation the temperature must rise at the earth's surface. The ascent of the morning of April 11, 1901, shows in fact such a temperature rise, though it is difficult to discover how far this is to be ascribed to the undercoming warm air or to the radiation of the sun; at any rate the first-named influence is not excluded.

When the fog reaches such a thickness that it becomes a great hindrance to the radiation of dark heat from the earth, its upper surface will take up the rôle of the earth, and further cool itself through radiation to the clear sky. Then appear the condition curves, which in a former part of this essay are characterized by the phrase, " completed fog below, but developing further above."

Their distinctive features, to recapitulate them briefly, are: temperature decrease upward, slowly becoming a zero gradient and finally an increase upward; in the lowest part, vapor-air ratio (Mischungsverhältnis)[16] decreasing upward, which at the upper limit of the fog generally increases, with a coincident diminishing relative humidity and a slow increase of wind velocity in the upper fog strata. The upward temperature decrease in the lower portion, as heretofore indicated, is due to the fact that the upper fog layers are cooled faster than the earth's surface, whose radiation is impeded. If the gradient exceeds 1° per 100 meters lively vertical movement will begin in the fog, which will bring down the cold of the upper layers, and cause a further cooling of the air at the earth's surface, which will now progress in like manner as the temperature reduction of the upper limit, and, therefore, is only an indirect result of radiation. The fog droplets will be evaporated by descent from the higher layers and will raise the vapor pressure at the earth's surface, while in compensation the saturated air from the ground, rising above, will soon precipitate the water and lower the absolute humidity. Therefore, it follows that the density of the fog increases upward, and reaches its maximum at the upper limit; whence it provides an easy explanation of the noteworthy fact that the balloon, at first occasionally and then fully disappears in a fog when its height must have already passed that of the fog.[17]

For example, the balloon on November 4, 1901, was yet visible at 100 meters.

The distribution of temperature and moisture at that point would permit hardly 100 meters for the thickness of the fog layer.

Atmospheric conditions on November 4, 1901.

Height in meters.	Temperature, ° C.	Per cent of relative humidity.
8	—2.5	100
18	—2.5	95
99	0.5	88

On December 20, 1901, the balloon disappeared between 150 and 200 meters, while the minimum temperature lay at 171 meters. Also the wetting of the cable by water droplets first occurs in the higher layers. The lower portion was always dry when we had thick fog at the earth's surface. Thus, for

[13] Homén. A. a. O. S., 172.
[14] Köppen. Die Bildung von Bodennebeln, Met. Zeitschr. 1885. P. 30.
[15] Wiss. Luftf. II. P. 202.

[16] In the original tables and text, absolute humidity values are given as the amount, x, of vapor found in combination with one kilogram of dry air, i. e., in $(1 + x)$ kilogram of moist air. Von Bezold applied the term " Mischungsverhältnis " to such quantities. The literal English equivalent "combining ratio " seemed to be not so suggestive as "vapor-air ratio."—*Translator.*

[17] A maximum density at the upper surface of the fog would not alone seem to explain the transient disappearance of the balloon before the final disappearance. Perhaps the author intends that the reader shall associate with this cause the wave movement at the upper surface of the fog, or the varying density of the fog in a horizontal direction.—*Translator.*

example, on October 28, 1901, when 550 meters of cable were in the air, only the uppermost 200 meters were wet, and on November 4, out of 950 meters, only 600 meters. The zero vertical temperature gradient (Isothermie) in the upper part of the fog is the result of mixing with the part at the earth's surface when the fog has already reached a certain density. But if the temperature underneath the overlying strata falls, they will also cool more and more during the course of the night, and, indeed, not alone by conduction and radiation, but essentially by the mixing of air masses of different temperatures if different wind velocities bring it about, as the larger vapor-air ratio over the fog proves. The cooling thereby resulting will then also extend down from the upper height, and will proceed relatively fast. The evening ascent of December 20, 1901, furnishes an interesting illustration thereof, at which, while the balloon was at the same height, within a short time substantial temperature decrease over the fog was observed.

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The thermograph curve lets this fall be seen very plainly. Whether, up to the 21st, the fog limit had risen can not be stated with certainty; but, on the other hand, a further fall of temperature over the fog up to the upper current is proved beyond doubt. In one case only is an increase of thickness of the fog layer during the night indicated with certainty, viz, from the 27th to the 28th of October, 1901, when the upper limit rose from 175 meters to about 250 meters.

This slow growth can not surprise one, for it has already been emphasized that the fog owes its birth to the air billows at the earth's surface which have been produced by wind differences, and likewise proceed up to the greater heights tolerably quickly. Naturally because of small wind "gradients" (if I may so express it, in analogy to temperature gradients) at the higher elevations, in contrast to the strong ones at the earth's surface, small billows only will occur at the upper fog surface. As already shown in a preceding chapter this appears not to exceed 70 meters height, and therefore energetic condensation thenceforth will hardly be able to proceed. In general the result of radiation during the night will manifest itself in an increasing density of the fog, and only a small increase of height.

This further formation of fog will probably go on at the top of the billows. On the one hand the temperature of the fog is there the lowest, and, at the same relative humidity, condensation through mixture proceeds first at the greatest temperature differences; on the other hand this mixing will be favored by the form of the wave crests. For we must picture to ourselves that a shooting over (Überschlagen) of these crests occurs not only very frequently, but indeed constantly, because the density of the lower media shows very little difference from those flowing over them. The overshooting and the accompanying drifting out of the cold air into the warm has often been observed in balloon ascensions, namely, in the fog banners produced by the billow crests, which are borne along by the wind and are later evaporated. If now in this manner the upper layer attains a certain degree of moisture, then, with further temperature fall condensation will set in, and the upper surface of the fog be raised. It is obvious, however, that this can go on but slowly, for a portion of the fog is always evaporated again.

A limit is set to further fog formation, if all other conditions favor progress, as soon as the fog fills the whole lower layer, and its upper surface reaches the higher-lying, warm, and most important of all, dry air current. On the 21st of December, 1901, this appeared to be nearly the case; the slight inversion which showed itself above the cloud would soon vanish by further cooling. Whether this maximum of fog height was really reached can not be said, for by reason of the breaking away of the kite balloons on December 21, the observations unfortunately were interrupted for a time. Such a growth will be favored by a long night in which radiation can go on uninterruptedly. Probably, therefore, in higher latitudes, especially in the polar regions, fog will have a considerably greater thickness than with us.

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The appearance of fog on October 27, 1901, offers an essentially different form. While generally fog appears in a place and grows gradually, this one in the rapidly coming darkness on the 27th of October, arose out of the west already complete in the form of a cloud bank, and on its arrival had already attained considerable density, which was especially curious, and for that reason was noted. The condensation was so energetic that the water ran down the cable in streams, and the range of sight at the earth was hardly 50 meters. The condition-curve of temperature has the typical form for fog at the beginning of its development, viz, a quick temperature fall close over the earth, but decreasing slowly farther up. The humidity curve shows saturation up to the fog limit, which lay at about 170 meters, and also a high value above, near 80 per cent. The air movement is brisk in the fog; over it, feeble. A continuous succession in height of the meteorological elements gives the full explanation of the sudden appearance of this fog, as the figs. 34-37 show. [Figures are omitted.] They disclose, up to the afternoon of the 27th, a relatively warmer, drier, and feebly-moving air current flowing over the observatory; toward 5 o'clock, there suddenly entered a cooling up to at least 700 meters, but probably still higher. Simultaneously, the relative humidity rose (the vapor-air ratio had been increasing continuously since morning), and the wind freshened. We have here to do with a complete weather change in the whole explored layer, for the nearly parallel course of the curves of humidity, vapor-air ratio, and wind velocity indicate the breaking in of a stream of entirely different composition.

The weather change which is identified with the cold, moist, and thereby actively-moved air current made itself perceptible near the earth's surface in the night of October 26-27. While, therefore, the air at the earth's surface was relatively dry, on the evening of the 26th the relative humidity came up to over 90 per cent, and the line of equal relative humidity rose gradually in the course of the night. Above, it was dry up to midday of the 27th. The march of temperature showed on the morning of the 27th, between 200 and 400 meters, a disturbance in the form of an isothermal layer which could be traced not alone to a cooling of the earth's surface during the night, and which still existed in the evening in the same manner. The constancy of the temperature at 200 and 500 meters is surprising. At 500 meters it was practically the same at midday and evening. At about 200 meters it had fallen only about 0.1°. At greater heights a gradual fall showed itself. In the dry layer, which was not only relatively but absolutely dry, as results from the mixing ratios, nearly complete calm prevailed; thereunder was feeble movement of a little more than two meters per second. The slow advance of the lower air current is noticeable in the gradually rising lines of equal relative humidity and wind velocity; and it needed only a slight fall of temperature to bring about condensation of the water vapor, for at 4 p. m. the dew-point at about 100 meters was only 6.5°, while the air temperature was 8°. About 5 p. m. the cold current approached with a wind velocity of 5 to 6 meters per second in full strength, and caused sudden fog formation, which moved on with the wind from west toward east. Thus the fog arrived at Landsburg, which lies about 120 kilometers almost due east from Berlin, about 11 p. m., i. e., it extended itself with a velocity of about five and one-half meters per second, which the registered wind velocity fully shows.

Especially noticeable here is the wedge-shaped figure of the

cold stream, which H. Helm Clayton has already mentioned, and which has since been often observed at the observatory.

The whole phenomenon had much resemblance, as well in its approach as also in the distribution of temperature and moisture, to the earlier mentioned inflowing fog stream from the Pacific Ocean through the Golden Gate, which has been several times observed and described by McAdie.[18]

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The formation of fog on November 4, 1901, is a pure example of mixture as von Bezold has studied it. The entirely irregular march of temperature in the morning [cold below, warmer above all the forenoon] permits the conclusion that here two air currents of different temperatures flow one under the other, and this produces a noteworthy distribution of temperature. If this occurs in sufficient proximity to the condition of saturation, then condensation occurs. The fog formation began in the morning and, in spite of increased insolation, continued until evening, when the fog reached the imposing height of 340 meters. The irregular temperature march had now given way to a regular one, and overhead the condition curves showed no surprising differences from the others which in the fog had become those unusually giving rise to fog. The warm and absolutely moist, but relatively dry air column with tolerably active movement [over seven meters per second] flowed this time over the one with less vapor, and on midday of the 4th, as can be seen by the curves of wind velocity and relative humidity, made an energetic push downward whereby, through mixing with the underflowing current, condensation ensued. Thereby the vapor-air ratio naturally decreased, and thus there resulted in the fog a relatively smaller water content.

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It may be said by way of recapitulation that most of the fog over the north German lowlands results from the flowing away of a moist air current over the earth's surface, which has been cooled by radiation, in such a manner that the lower cold air layers are tossed up (geschleudert) by the accompanying formation of billows, which occurs in winds near the earth, and which, by the mixture of the upper and lower layers, precipitates the fluid water. More rarely fog proceeds from the mixture of two moist currents of different temperature.

THREE NOTABLE METEOROLOGICAL EXHIBITS AT THE WORLD'S FAIR.

By James H. Spencer, Observer, United States Weather Bureau.

THE UNITED STATES WEATHER BUREAU.

The United States Weather Bureau exhibit occupies about 1000 square feet of floor space in the west end of the Government Building. Fronting, as it does, upon the main aisle, the exhibit is one of the most conspicuous in the building.

Ten instruments are operated by storage batteries, and several of them are connected to two or more registers. The outside temperature is recorded indoors by a telethermograph; the rainfall by a pluviograph; and the rainfall, sunshine, and wind velocity and direction by a station meteorograph. In order to show the method of operation, duplicates of these three registers are also connected electrically on short circuit with instruments within the exhibit space. Among the other instruments displayed are a set of self-recording thermometers, sling and whirling psychrometers, river gages, thermograph, barograph, single and double magnet registers, photographic and thermometric sunshine recorders, electric pyrheliometer, seismograph, mercurial and aneroid barometers, and a kite meteorograph, anemometer, and nephoscope. These instruments have already been fully described in various Weather Bureau publications.

[18] McAdie. Fog Studies on Mount Tamalpais, Monthly Weather Review, 1900, Nos. 7 and 11; 1901, No. 2, and Proceedings of the Second Convention of Weather Bureau Officials, 1903, p. 31.

A full-size Weather Bureau kite, with instruments in position, is suspended from the ceiling and connected with a reel in the usual manner.

Forecast cards are printed daily on a Harris automatic press, which has a capacity of about 15,000 per hour. These cards, and also a typical weather map and other printed matter, are distributed to visitors.

A large relief map of the United States gives the distribution of annual precipitation throughout the country. Two sets of swinging frames each contain eighteen charts or photographs, showing the climatology of the United States, cloud forms, floods, instruments, and other instructive matter.

A model storm-warning tower is displayed, with lanterns and a special hoisting attachment in position. The full-size oil-burning and electric lanterns are also exhibited.

The feature that perhaps attracts the most attention is the glass weather map. The reports are telephoned from the downtown office as fast as received by telegraph, and by 10 o'clock each morning the state of weather, current temperature, direction of wind, and rainfall from 122 stations are charted in different colors; the isobars are drawn in white. The weather conditions in all sections of the country are thus strikingly shown.

THE GERMAN EXHIBIT.

The German meteorological exhibit may be found in room D, German section, of the Educational Building. A large amount of self-recording apparatus is displayed, but perhaps the exhibits of greatest interest are the kites, rubber balloons,
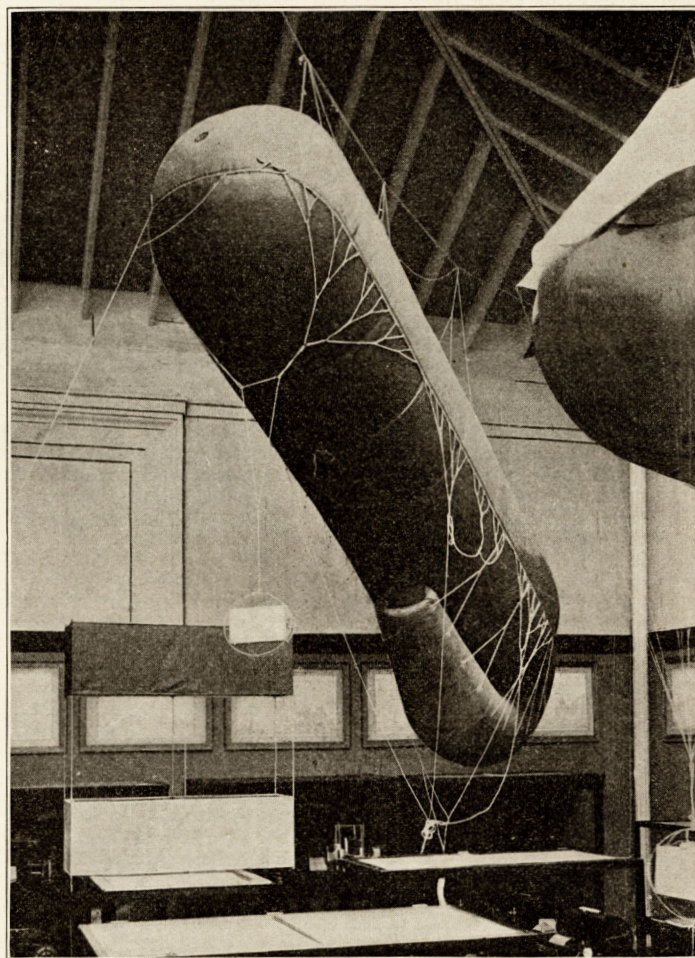

Fig. 1.—Rubber balloons.

kite balloons, and their accessories. The central figure in the accompanying photograph is the kite balloon, by the use of